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Fumigation of Vetch Seed for the Vetch Bruchid

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INTRODUCTION

The vetch bruchid (*Bruchus brachialis* Fahraeus) is found throughout the vetch-growing district of the Middle Atlantic seaboard. It was discovered at Haddon Heights, N. J., on June 24, 1930, by L. J. Bottimer; it has since been found in other parts of New Jersey [2] and in Delaware, Pennsylvania,[3] Maryland, Virginia, North Carolina, South Carolina, Georgia, and the District of Columbia.

According to Pinckney,[3] infestation by this insect may result in a heavy reduction in yield of vetch seed. It is considered a serious

[1] The writers are indebted to W. B. Wood, of the Division of Foreign Plant Quarantines of the Bureau of Entomology and Plant Quarantine, who carried on some of the earlier experiments, and to other members of the staff of that Division for cooperation in the work, particularly for help in fumigation, for data, and for samples of fumigated seed. The writers are also indebted to the Division of Seed Investigations of the Bureau of Plant Industry, U. S. Department of Agriculture, for making several series of germination tests of fumigated vetch seed.

[2] BRIDWELL, J. C., and BOTTIMER, L. J. THE HAIRY-VETCH BRUCHID, BRUCHUS BRACHIALIS FAHRAEUS, IN THE UNITED STATES. Jour. Agr. Res. 46: 739–751. 1933.

[3] PINCKNEY, J. S. THE VETCH BRUCHID, BRUCHUS BRACHIALIS FAHRAEUS. Jour. Econ. Ent. 30: 621–632, illus. 1937.

pest, and a number of the Western States in which this insect is not known to be present, have established quarantine regulations against vetch seed from the Eastern States.

Considerable vetch seed is imported into the United States, principally from European sources, and these shipments may be infested with this bruchid or with other species of *Bruchus*. In the season of 1933–34, 3,000,000 pounds were imported. There is danger, therefore, of spreading infestation from seed grown in the eastern part of the United States or from foreign-grown seed and of introducing other bruchids.

The importance of destroying the vetch bruchid in seed that was to be planted in areas where this insect did not occur was recognized, and work on methods of treating the seed which would free it from insects without damage to the seed was begun in 1934 and continued through 1937. The work consisted in developing methods of fumigation which could be applied under commercial conditions to vetch seed grown in this country or to imported seed.

MATERIALS AND METHODS

The general method employed in these experiments was to place small lots of infested seed in muslin bags in a sack or package of vetch seed, to fumigate, and to work out the dose, duration of exposure, and temperature at which the treatment should be applied to produce a complete kill of the insects. After a preliminary survey was made, small packages of vetch seed heavily infested with the bruchid were inserted at the approximate center of commercial packages, the 100- or 220-pound sacks of vetch seed. The sacks of seed were then fumigated according to various methods and the effective dose determined. Two fumigants, hydrocyanic acid and carbon disulfide, were used, and two methods of fumigation with hydrocyanic acid, viz, fumigation under atmospheric pressure and under reduced pressures, were employed. Details of the experimental work will be discussed later in connection with the various experiments.

EXPERIMENTAL WORK

Fumigation Under Reduced Pressure

The first work was carried on in Washington, D. C., in 1934, by W. B. Wood, who tested the effect of fumigation under reduced pressures with both carbon disulfide and hydrocyanic acid.[4] He used small quantities of infested seed shipped in from North Carolina for that purpose; in some cases he buried the infested seed, contained in cloth-covered vials, in sacks of vetch seed; when a sufficient quantity of vetch seed was lacking, he used sacked wheat with the infested seed inserted at the approximate center of the sacks. His work indicated that complete mortality of the insect could readily be obtained with either one of these fumigants. It was further demonstrated that high concentrations of both hydrocyanic acid and carbon disulfide could be applied with little or no effect on the viability of the seed. It was found that up to 25 pounds of carbon disulfide per 1,000 cubic feet for a period of 2 hours under reduced pressures had

[4] Carbon dioxide was mixed with the carbon disulfide until atmospheric pressure was reached.

practically no effect on the germination of the seed of either hairy vetch, smooth vetch, or common vetch, and that 18 ounces of hydrocyanic acid per 100 cubic feet for a period of 2 hours could be applied to hairy vetch and common vetch without injury to the seed.

The experimental work was continued during 1936 at Salisbury, N. C., which is in the vetch-seed-producing area, where infested seed could be obtained and it was possible to procure quantities of vetch seed for use as a load in the fumigation chambers. A small vacuum fumigation chamber of 13.3 cubic feet capacity, with chamber and pump portable, was used for the fumigation at reduced pressures. A portable chamber of 100 cubic feet capacity for fumigation under atmospheric pressures was constructed of galvanized-iron sheets on a frame of 2- by 2-inch wood, with gaskets at joints bolted together, so that the chamber could be easily taken down and transported. It was fitted with a small fan to stir the gas mixture within the chamber so as to provide a more even distribution of the fumigant. A portable water-seal drum fumigator was also used for the fumigation experiments with carbon disulfide where small quantities of vetch seed were to be treated at atmospheric pressures.

Fumigation experiments were carried on with hydrocyanic acid under reduced pressures and with both hydrocyanic acid and carbon disulfide at atmospheric pressures.

In the fumigation of vetch seed under reduced pressures two sacks of 100 pounds each were used in each load, which is approximately equivalent to a load of 1,500 pounds of seed per 100 cubic feet. The pressure within the chamber was reduced to the equivalent of 2 inches of mercury, and the hydrocyanic acid was volatilized by passing it through a copper coil submerged in hot water and thence into the fumigation chamber. The low pressure was held throughout the fumigation period of 2 hours. The results of 16 experiments are shown in table 1. In this work the number of live insects placed in each sack was estimated from counts of the number of live adults that emerged from 6 ounces of seed from the same lot. Some of the immature stages of the bruchid were also present in the seed.

TABLE 1.—*Fumigation of infested vetch seed at the rate of 1,500 pounds per 100 cubic feet, under pressure reduced to the equivalent of 2 inches of mercury, with liquid hydrocyanic acid*

(Exposure 2 hours)

Dosage per 100 cubic feet (ounces)	Temperature of sack	Seed sample at center of sack		Seed sample at top of sack		Dosage per 100 cubic feet (ounces)	Temperature of sack	Seed sample at center of sack		Seed sample at top of sack	
		Estimated insects killed	Actual insects surviving	Estimated insects killed	Actual insects surviving			Estimated insects killed	Actual insects surviving	Estimated insects killed	Actual insects surviving
	°F.	Number	Number	Number	Number		°F.	Number	Number	Number	Number
3	84	852	6	426	0	6	82	466	1	233	0
3	82	956	1	478	2	7	79	688	0	344	0
4	85	852	2	------	------	7	80	650	0	325	0
6	84	458	0	229	[1] 1	7	73	650	0	650	0
6	80	458	0	229	0	7	80	650	0	650	0
6	82	466	0	233	0	8	75	688	0	688	0
6	84	466	0	233	0	8	78	650	0	650	0
6	80	932	0	466	0	8	80	650	0	650	0

[1] This insect was partly paralyzed; it died the following day.

From table 1 it is evident that complete mortality of this bruchid can be obtained in most cases with 6 ounces of hydrocyanic acid per 100 cubic feet, since only 1 adult survived in 6 experiments in which an estimated population of 4,869 adults were present. No bruchids survived fumigation with 7 or 8 ounces of hydrocyanic acid per 100 cubic feet. There was some survival when doses of 3 and 4 ounces were used.

Fumigation Under Atmospheric Pressure

In the experimental work on the fumigation of vetch seed with hydrocyanic acid at atmospheric pressure the 100-cubic-foot fumigation chamber was used. The liquid hydrocyanic acid was measured volumetrically, transferred to a glass beaker in the fumigation chamber, and volatilized by means of an electric heater. A small electric fan was used to circulate the air within the fumigation chamber. A dose of 3 pounds per 1,000 cubic feet was used in three different loads of vetch seed. The results are shown in table 2. In these experiments, also, the numbers of insects that were present in small quantities of heavily infested seed placed at various points in the load were estimated from the numbers in known quantities of seed from the same source.

Table 2.—*Fumigation of infested vetch seed, under atmospheric pressures, with hydrocyanic acid and carbon disulfide*

[Exposure 24 hours]

Fumigant used	Dose per 1,000 cubic feet	Temperature of seed	Load of seed per 1,000 cubic feet	Estimated insects killed in samples	Actual insects surviving
	Pounds	*°F.*	*Pounds*	*Number*	*Number*
Hydrocyanic acid	3	85	10,390	6,360	0
		80	12,500	9,100	0
		75	15,000	10,422	0
Carbon disulfide	40	80	12,000	690	0
	30	88	12,000	795	0
	25	78	12,000	858	0
	20	75	12,000	1,032	0

Table 2 shows that the treatment with hydrocyanic acid produced complete mortality in all cases with loads of seed ranging from 10,390 to 15,000 pounds per 1,000 cubic feet. The temperatures in all three experiments were 75° F. or above. The difference in load apparently did not affect the efficacy of the treatment at those temperatures.

The experiments with carbon disulfide are also shown in table 2. The tests were made in a small water-seal fumigator of approximately 8 cubic feet capacity. One hundred pounds of vetch seed was used in each experiment with an exposure of 24 hours. On the basis of 1,000 cubic feet of fumigation space the relative load would be approximately 12,000 pounds of seed. Doses of 20, 25, 30, and 40 pounds of carbon disulfide per 1,000 cubic feet were applied. No survival occurred in these tests.

TESTS WITH COMMERCIAL LOTS IN 1936

Work with commercial lots of imported seed was begun in 1936. In some of these shipments the bruchid population was sufficient to furnish data on the effect of the fumigation, in others it was necessary to place samples of infested seed in the sacks in order to determine the effect of the treatment on the insect. The conditions will be discussed when the fumigation of each lot of seed is considered.

In this work the fumigation was all under atmospheric pressure, as the shipments arrived at ports where no installations for fumigation under reduced pressure were available. Various kinds of chambers were used, some of which were efficient and some not, and this provided an opportunity for obtaining data on the type of chambers that are effective for fumigation of this product.

The work was carried on in cooperation with the Division of Foreign Plant Quarantines. In some cases samples of the fumigated seed were collected by the inspectors of that Division and forwarded to Washington for inspection. In others it was possible for some one of the writers to be present and observe the fumigation procedure. The shipments were fumigated at ports of entry as indicated in the discussion of the fumigation of each shipment. In some cases an entire shipment was fumigated as one load; in other cases it was fumigated in several lots, thus affording an opportunity for replicating experiments.

Shipment No. 1, Baltimore, Md., September 1936

Shipment No. 1 consisted of 22,000 pounds of vetch seed in 220-pound sacks. As the early experimental work had been conducted with sacks of seed, each containing 100 pounds, it seemed doubtful whether the fumigant would penetrate the mass of seed in sufficient quantity to kill the insects that might be present. An adequate fumigation chamber was not available, and a room approximately 25 feet long, 6 feet wide, and 10 feet high, with concrete ceiling and floor and brick walls, was used. The volume of this room was approximately 1,500 cubic feet. The sacks were placed in two rows, two sacks high, with timbers separating the upper and lower layers. Five pounds of liquid hydrocyanic acid contained in absorbent materials was used, making a dose of 3⅓ pounds of hydrocyanic acid per 1,000 cubic feet, with a load of approximately 15,000 pounds of seed per 1,000 cubic feet. The temperature of the seed was approximately 85° F. The period of exposure was 44 hours, and during this time the gas mixture was circulated by means of an electric fan.

Twenty-four hours after opening the room 12 half-pound samples of seed were taken from the outside and center of 6 sacks and held for observation and comparison with 2 samples removed before fumigation. Survival occurred in samples from the center of 2 sacks. The estimated population of live insects was 204, of which 10, or about 5 percent, survived. The room was unsatisfactory for fumigation purposes.

Shipment No. 2, Baltimore, Md., September 1936

Shipment No. 2, 11,000 pounds of vetch seed in sacks, each containing 220 pounds, was fumigated in a refrigerator car of approximately 2,600 cubic feet capacity, the sacks being placed lengthwise on the floor racks of the car. The dose was 8 pounds of liquid hydrocyanic acid, or slightly more than 3 pounds per 1,000 cubic feet, with a load considerably below the maximum used in the experimental work. The temperature of the seed was 81° F.; the fumigation period was 42 hours. No living bruchids were obtained from the samples of fumigated seeds. Since the load was small for the volume of space and the dose given was considerably higher than would be necessary for this quantity of seed if a smaller fumigation chamber had been used, it was thought possible that sufficient hydrocyanic acid might have been absorbed by the seed to have injured its viability. To check this point 10 samples of fumigated seed from different sacks and 2 samples of seed from the same lot before fumigation were submitted for germination tests. The average germination of the fumigated seed was 78 percent, and the germination of the unfumigated seed was 80 percent, a close agreement between two sets of random samples. These tests indicated no appreciable injury to the seed from the treatment.

Shipment No. 3, Norfolk, Va., September 1936

Shipment No. 3, consisting of 33,000 pounds of vetch seed in sacks of 220 pounds' capacity, was fumigated in a metal chamber, which was used for steam sterilization of bagging and other materials and had a volume of 2,670 cubic feet. Ten pounds of hydrocyanic acid in absorbent material was used, which is a dose of approximately 3¾ pounds per 1,000 cubic feet. The temperature of the seed was above 75° F., and a 48-hour exposure was given. Approximately 1 pound of seed was inspected from each of 16 sacks, and 8 of these samples were held to obtain any subsequent emergence. No live insects emerged, although 117 dead weevils were found among the seed.

Shipment No. 4, Charleston, S. C., September 1936

Shipment No. 4 consisted of 55,000 pounds of vetch seed, in sacks of 220 pounds' capacity, and was found on examination to be heavily infested with the bruchids. It was divided into 2 lots of 125 sacks each and fumigated in 2 refrigerator cars with carbon disulfide at the rate of 20 pounds per 1,000 cubic feet and with an exposure of 40 hours at temperatures above 75° F. At the conclusion of the fumigation several sacks were thoroughly examined and no living weevils were observed. Samples of the fumigated seed were held for subsequent examination and no live bruchids emerged therefrom.

Shipment No. 5, New Orleans, La., October 1936

Shipment No. 5 of vetch seed consisted of 164,500 pounds of vetch seed in sacks of 100 pounds' capacity and was fumigated in a commercial fumigation chamber which had a volume of 4,680 cubic feet. The shipment was divided into four lots, and each lot was fumigated

separately to avoid the labor in stacking the seed in the fumigation chamber with dunnage required for separating the layers of sacks. The hydrocyanic acid was generated by the "pot method," 1 part of sodium cyanide, 1 part of sulfuric acid, and 3 parts of water being used at the rate of 6 pounds of sodium cyanide per 1,000 cubic feet. Assuming the hydrocyanic acid equivalent to be half the weight of the sodium cyanide, the dose applied for the chamber was 3 pounds of hydrocyanic acid per 1,000 cubic feet. In the fumigation of the seed the temperature was above 75° F. throughout. Load No. 1 (55,000 pounds) had an exposure of 38 hours; load No. 2 (36,000 pounds), 39 hours; load No. 3 (36,000 pounds), 46 hours; and load No. 4 (37,500 pounds), 41 hours. Inspection of samples of the fumigated seed showed no live weevils, and in the samples held no live weevils emerged.

TESTS WITH COMMERCIAL LOTS IN 1937

In the commercial treatments during 1936 the infestation in the imported vetch seed was relied on to show the effect of the fumigant. However, the imported material was not usually heavily infested, so in many cases sufficient numbers of insects were not present to furnish reliable evidence on the effect of the treatment. In 1937 a supply of heavily infested domestic seed was obtained in June. This was stored under refrigeration at a constant temperature of 50° F., and samples of this infested seed were placed in the shipments of foreign seed, when possible, to determine the effect of the treatment on the weevil. The samples were prepared by placing about three-fourths of a pound of seed in cheesecloth sacks of sufficiently fine mesh to prevent the weevils from escaping. These samples were placed near the center of several sacks prior to fumigation, strings or cords being attached to the samples so that they could be readily removed. From 50 to 150 live insects were present in each sample.

Shipment No. 6, Baltimore, Md., September 1937

Shipment No. 6 consisted of 33,000 pounds of vetch seed in sacks of 220 pounds' capacity. The shipment was divided into 2 lots and fumigated in 2 refrigerator cars, 75 sacks to each car. The temperature of the seed was 75° F. Infested samples as just described were placed in 26 sacks of the vetch seed. Eight pounds of hydrocyanic acid in absorbent material was used per car, which was approximately 3 pounds per 1,000 cubic feet. The fumigation period was 24 hours, but the infested samples were allowed to remain in the sacks of vetch seed until 2 days later to simulate as nearly as possible commercial conditions in which the residual hydrocyanic acid absorbed by the seed in the commercial shipment might have an effect on the vetch weevil. These samples were held for emergence and no live weevils emerged; 2,560 dead weevils were recovered.

Shipment No. 7, Baltimore, Md., October 1937

Shipment No. 7 consisted of 22,000 pounds of vetch seed in sacks of 220 pounds' capacity. It was treated in a well-constructed fumigation vault of a capacity of 720 cubic feet. The shipment was divided into 2 lots and each lot was fumigated separately. A fan in the

vault circulated the hydrocyanic acid and air mixture produced by using 1 part of sodium cyanide, 1½ parts of sulphuric acid, and 2 parts of water. The temperature of the seed was 65° F. The dose of sodium cyanide was equivalent to 3 pounds of hydrocyanic acid per 1,000 cubic feet, and the period of fumigation was 24 hours. Infested samples of domestic seed were placed in 12 sacks before loading. Of the 1,097 weevils recovered from the samples, 65 were alive. Four of the samples showed 100 percent kill, but the remaining 8 contained survivals of from 1 to 27 percent. This indicated that a temperature of 65° was too low for fumigation with this dose. Before it was discovered that survival occurred the second lot of vetch seed in this shipment was fumigated at a seed temperature of 66°. Five of the twelve samples of infested seed placed in the sacks showed 100 percent mortality. The remaining samples had from 1 to 13 percent survival. These 2 tests showed that this treatment was not effective in killing the weevil at this temperature.

Shipment No. 8, Baltimore, Md., October 1937

Shipment No. 8, 33,000 pounds of imported vetch seed, was found to be infested. The temperature of the seed near the center of the sacks was 56° F., and arrangements were made to place the sacks in a heated room and raise the temperature to at least 70°. This required about 2 days. The same fumigation vault was used as for shipment No. 7, and the seed was divided into 3 lots. For the first lot the dose was increased to the equivalent of 5 pounds of hydrocyanic acid per 1,000 cubic feet with a 24-hour exposure. Infested samples of domestic seed were placed in 12 sacks, and from these 1,001 dead bruchids were recovered, with no survivals. The second lot of 50 sacks was fumigated on October 21, the temperature of the lot being 70°. A dose equivalent to 4 pounds of hydrocyanic acid was used in this treatment, and 912 dead weevils were recovered from the 12 samples of infested seed within the sacks, with no survivals. On October 23 the third lot of 50 sacks was treated at a temperature of 70°, and a dose equivalent to 4 pounds of hydrocyanic acid per 1,000 cubic feet was applied for a period of 24 hours. In 12 samples of infested vetch seed placed in the center of the 12 sacks 934 dead bruchids were found, with no survivals.

A number of germination tests with fumigated and unfumigated seed from various experiments showed no appreciable difference in viability due to fumigation with hydrocyanic acid at any of the concentrations used.

DISCUSSION

From the results of the experimental work given in the foregoing pages it is obvious that any one of the three methods of fumigation is effective in destroying *Bruchus brachialis* in infested vetch seed. It was not possible to test the method of fumigation with hydrocyanic acid under reduced pressure on a commercial basis, as equipment for fumigation by this method was not available at the ports through which the vetch seed was imported. From the experimental work, however, there is no question as to the efficiency of this treatment at the proper dosage and temperature.

One shipment divided into two lots was fumigated with carbon disulfide with good results, and the rest of the commercial shipments

were fumigated with hydrocyanic acid under atmospheric pressures. It was evident from the results that the effectiveness of this latter fumigant varied with the temperature. In a number of the commercial fumigations the dosage was higher than required, as indicated by the results of the experimental work; also, the period of fumigation was longer than necessary. From the results in shipments Nos. 7 and 8 it is evident that complete mortality in large sacks (220 pounds) cannot be assured with a dosage of 3 pounds of hydrocyanic acid per 1,000 cubic feet and a full load of 15,000 pounds per 1,000 cubic feet in the chamber at a temperature of 65° F. Complete mortality was obtained in all commercial fumigations at 70° or above with a dosage of between 3 and 4 pounds of hydrocyanic acid per 1,000 cubic feet, except in the first lot, which was treated in a defective fumigation chamber. This emphasizes the necessity for a tight fumigation chamber, and, where possible, a means of circulating the air-hydrocyanic acid mixture. It may not be possible to provide fans in all cases, and, as shown in this work, complete mortality of the insect occurred in fumigations in refrigerator cars with a light load and without means of agitating the air. When a full load of 15,000 pounds per 1,000 cubic feet is being fumigated the air-hydrocyanic acid mixture should be circulated so that it will come in contact with the exterior of all sacks. The sacks should be separated from each other on all sides, and, if stacked two by four or four by four, dunnage should be used between the layers. A dry refrigerator car in good condition is a good fumigation chamber. In using the car the drains should be stoppered and plugs should be firmly seated in the hatchways so that no leakage occurs. The dosage should in all cases be calculated on a basis of 4 pounds per 1,000 cubic feet without regard to the load in the chamber (except that the load should not be more than 15,000 pounds per 1,000 cubic feet), and the exposure should be 24 hours at a temperature of 70° F. or above.

In fumigation under reduced pressure, the pressure within the chamber should be reduced to the equivalent of 2 inches of mercury, a 28-inch vacuum under normal atmospheric pressures at sea level, and a dosage of 7 ounces of hydrocyanic acid per 100 cubic feet of chamber space should be used at a temperature not lower than 70° F. The reduced pressure should be held throughout the fumigation period of 2 hours.

When carbon disulfide is used at atmospheric pressure a dosage of 20 pounds [5] of carbon disulfide per 1,000 cubic feet of chamber space should be applied, volatilized within the chamber, and agitated when possible for 2 or 3 hours after starting the fumigation. The temperature should not be lower than 70° F., and the load should not be more than 12,000 pounds per 1,000 cubic feet. The sacks of seed should be separated in all cases.

It should be emphasized that hydrocyanic acid is a deadly poison, and adequate precautions, including the use of gas masks, should be taken in using it. Carbon disulfide is also poisonous and is highly inflammable. It should not be liberated near an open flame or fire of any kind, including lighted cigars, cigarettes, or pipes, nor where there is danger of an electric spark.

[5] Table 2 shows that the minimum dosage is not known.

SUMMARY

In experimental work on the fumigation of vetch seed for the vetch bruchid (*Bruchus brachialis*) three methods were developed which gave complete mortality of the weevil in infested seed without apparent injury to its viability. These were (1) fumigation with hydrocyanic acid at atmospheric pressures, (2) fumigation with hydrocyanic acid at reduced pressures in a partial vacuum, and (3) fumigation with carbon disulfide at atmospheric pressures.

A number of commercial shipments were fumigated with hydrocyanic acid and with carbon disulfide with complete mortality of the weevil in all cases in which the temperature of the seed was 70° F. or above, and the room, car, or chamber in which the fumigation was conducted was satisfactorily tight.

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